DISTRIBUTION OF ENERGY IN THE VISIBLE SPECTRUM OF AN ACETYLENE FLAME*

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CONTENTS

I. INTRODUCTION

Data on the distribution of energy in the visible spectrum of a standard source of light are frequently needed by experimenters who are not in a position to determine for themselves the energy distribution. Frequent requests for such data have come to this Bureau and an attempt has been made to supply the desired information.

The acetylene flame appears to be a promising light source, having a high intensity and a white color. During the past six years the distribution of energy in the visible spectrum of this flame has been subjected to numerous investigations.

In a previous communication[1] data were published on the spectral energy distribution of a flat acetylene flame radiating

* Additional copies of this publication may be procured from the Superintendent of Documents, Washington, D. C., at 5 cents per copy.

[1] Coblentz, this Bulletin, 7, p. 243, 1911; reprinted in vol. 9, p. 109, 1912.

edgewise into the slit of a mirror spectrometer, containing a fluorite prism and a vacuum bolometer. The energy distribution in the region of the spectrum from the blue to the extreme violet was obtained with a spectrometer containing plano-convex lenses and a quartz prism. The investigation showed that the energy distribution was a function of the thickness of the flame. This variation of emissivity with thickness of the flame was found to be very marked in the infra-red, and continued to be appreciable into the visible spectrum—at 0.68μ.

The demand arising for more precise data, the investigation was undertaken anew in 1913, using more sensitive radiation instruments, which permitted making more precise measurements in the blue and violet parts of the spectrum. It was then found that in the flat acetylene flame, observed flatwise and also edgewise, the variation in emissivity with thickness was even more marked throughout the spectrum than previously recorded. From this it appears that the distribution of energy in a flat acetylene flame can not be standardized. However, the cylindrical flame from a specified burner seemed to give sufficiently concordant results to warrant its use as a standard of light for investigations which do not require the highest attainable precision, in the spectral energy distribution.

Important optical work, employing light stimuli, is being done with spectrometers having collimating lenses of glass and of quartz. The question arose as to whether the energy distribution can be determined with an achromatic doublet, and especially with a plano-convex quartz lens, provided corrections are made for changes in aperture with change in wave length. The investigation of the plano-convex quartz lens for spectral energy distribution as compared with a mirror spectrometer (which is the recognized method for making spectral-energy measurements) was made about two and one-half years ago; but the data were not published.

Recently in connection with an investigation of the visibility of radiation, a wide aperture, achromatic doublet (computed by E. D. Tillyer) was subjected to test for spectral energy distribution. The data obtained are in complete agreement with those obtained with the mirror spectrometer, and also with the spectrometer having plano-convex quartz lenses. These data are not in agreement with those previously published [2] on the flat flame

[2] This Bulletin, 7, p. 243; 1911.

viewed edgewise. The former data are therefore withdrawn in view of the difficulty in using a flat flame, viewed edgewise, and in view of the apparently greater reliability of the present data on the cylindrical flame of the dimensions specified. In giving the new data it is to be emphasized that whenever possible the energy distribution of the acetylene flame used should be determined experimentally, at least in the red and yellow part of the spectrum, where the intensity is high (hence easy to observe) and is subject to variations (in the red) with thickness of the radiating layer of the flame. In the region of the spectrum extending from the yellow to the extreme violet the energy distribution of all acetylene flames, whether cylindrical or flat (examined flatwise and edgewise), was found to coincide, indicating that the radiation is sufficiently saturated so that the data given herewith may be considered applicable to the various acetylene burners commonly used.

However, as already stated, in the region from the red toward the longer wave lengths the emissivity is greatly affected by change in thickness of the flame so that it is important to use a cylindrical flame of the dimensions specified in order to insure accuracy.

II. EXPERIMENTAL DATA

1. THE ACETYLENE FLAME

The data given in this paper pertain to a cylindrical acetylene flame, produced by a single-jet "Crescent *Aero*" burner,[3] consuming one-fourth cubic foot of gas per hour. The acetylene gas was made from commercial calcium carbide. It was produced by an automatic generator[4] and supplied to the burner under a water pressure of 7.5 cm (as measured at the outlet).

The automatic generating apparatus supplied the gas at a very uniform pressure, which is important in accurate work.

The height of the luminous part of the flame, as measured from the lava-tip burner, was about 3.5 cm and the thickness was about 3 mm. No doubt other makes of burners giving a flame of the dimensions herein specified will give similar results. In the recent investigation the flame was placed a short distance (about 15 mm) from the spectrometer slit, which was either 4 or 12 mm in height. In this manner the spectral energy distribution of a height of 4 mm and of 12 mm of the thickest part of the flame was obtained. (See Fig. 1.)

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[3] Obtained from the Crescent Burner Manufacturing Co., New York.

[4] A "Pilot, Model D," acetylene generator made by the Acetylene Apparatus Mfg. Co., Chicago, Ill.

The acetylene flame has been employed in this Bureau in radiometric investigations extending over a number of years, and it has proven a very convenient and constant source of radiation. A photometric investigation of the acetylene flame as a source of light for standardizing photographic plates, made by Jones,[5] also shows a great constancy in the behavior of this (flame) source of radiation.

The acetylene flame is, of course, subject to agitation by air currents, but it is easily rendered steady by the simple device of having it situated at a distance of about 3 mm from a sheet of metal, which is perforated by a slit 2 mm wide and 6 to 12 mm high, depending of course upon the use to which the flame is to be put for illumination. Such a simple shield, shown in Fig. 2 *A*, has been used satisfactorily in the various investigations made in this Bureau during the past six years. In order to make a light-tight inclosure a shield has recently been provided which is of the form shown in Fig. 2 *B*. However, for steadying the flame the device does not appear to be any more efficient than a strip of sheet iron, about 15 cm long and 10 cm wide, bent into the form shown in Fig. 2 *A*.

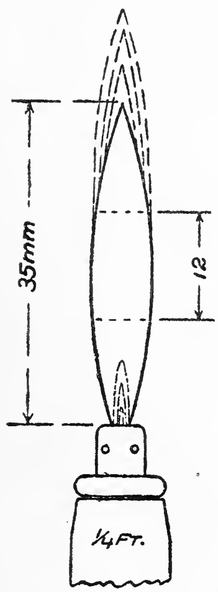

FIG. 1.—*Acetylene burner and flame*

2. THE SPECTRORADIOMETERS

The data presented in this paper are based upon the spectral energy distribution obtained with three different types of spectroscopes differing widely in dispersion and differing entirely in construction of the optical parts.

Spectroradiometer No. 1.—The spectroradiometer having the smallest dispersion and the highest intensity of radiation consisted of (1) a pair of plano-convex quartz lenses (cut perpendicular to the optic axis) 18 cm. in focal length and 6 cm. in diameter, (2) a 60° quartz prism, and (3) a radiometer consisting of a bismuth-silver thermopile and auxiliary galvanometer, both of which instruments have been described in previous communications in this Bulletin. In order to obtain a normal spectral energy curve from the data obtained with this outfit it is necessary to apply corrections (1) for reflections from the faces of the prism

[5] Jones, Trans. Illum. Eng. Soc., 9, p. 716; 1914.

and the lenses (column 6, Table 1), (2) for change in slit width with change in focal length (column 5, Table 1), and (3) for change in energy intercepted with change in aperture with focal length. The latter correction is important because the factor enters as the square of the focal length. These data are given in column 7 of Table 1. The complete data for reducing the prismatic energy distribution to normal are given in column 8 of Table 1. They are to be considered supplementary to the optical constants of quartz previously published.[6] The distribution of energy in the spectrum, obtained from the observations when using this quartz spectrometer outfit, is given in Fig. 3. The data are in excellent agreement with those obtained with other spectroradiometers having a much larger dispersion. In the extreme violet the energy is probably a trifle high, due to the presence of diffuse light.

TABLE 1

Data for Reducing Prismatic Spectral Energy Curves to Normal when Using a Spectroradiometer Consisting of a 60° Quartz Prism and a Pair of Plano-Convex Quartz Lenses Having a Focal Length of 18 cm for $\lambda=0.5876\mu$

Spectrometer setting	Wave length	Focal length	Angular slit width for different focal lengths	Slit width corrected for change in f. l. =S.W.	Transmission; $\frac{(1-r_1)^6\times(1-R_1)^2+(1-R_2)^2}{2}$ =T	$\left(\frac{1}{f\lambda}\div\frac{1}{f.587\mu}\right)^2=\frac{1}{f_1^2}$	$SW\cdot\frac{1}{f_1^2}\cdot T$
° '	μ	mm	'	μ			
−0 30	0.7828			0.0880	0.6678	0.9562	0.0562
K	.7665	184.0	9.79				
25	.7398			.0789	.6669	.9640	.0507
20	.7020			.0706	.6661	.9720	.0457
15	.6681			.0634	.6653	.9745	.0411
He	.6678	182.1	9.90				
10	.6383			.0570	.6646		.0372
− 05	.6119			.0513	.6637		.0338
0 00	.5876	180.0	10.00	.0464	.6629	1.000	.0308
+ 05	.5654			.0419	.6621		.0278
10	.5451			.0380	.6612		.0254
15	.5269			.0343	.6604		.0233
20	.5111			.0317	.6597		.0215
He	.5015	176.9	10.17			1.035	
30	.4830			.0270	.6581		.0186
40	.4591			.0233	.6565		.0162
He	.4472	173.8	10.34			1.074	
50	.4378			.0203	.6549		.0145
+1 00	.4193			.0180	.6533		.0130
10	.4029			.0161	.6516	1.115	.0117
He 20	.3889	170.0	10.65	.0144	.6500	1.121	.0106
30	.3764			.0131	.6485		.0099
40	.3652		10.85	.0120	.6471		.0091
50	.3550			.0111	.6455		.0085
+2 00	.3452			.0102	.6439	1.212	.0080

This Bulletin, 11, p. 471; 1914.

Spectroradiometer No. 2.—The second outfit used in the energy measurements in the spectrum of the acetylene flame consisted of a spectrometer with (1) silvered-glass mirrors 50 cm. in focal length, (2) a perfectly clear, 60°, fluorite prism, and (3) a vacuum bolometer. This outfit has been described in a previous communication,[7] in which data are given for eliminating the absorption in the silver mirrors and for reducing the observations to a normal spectrum. In a mirror spectrometer the question of achromatism does not enter into the work, and the change in astigmatism is inappreciable. Owing to the larger dispersion which obtained in this spectroradiometric outfit (about twice that of spectroradiometer No. 1) and the small aperture of the prism, the energy measurements could not be extended into the extreme violet. The data are in excellent agreement (Fig. 3) with those obtained with the other spectroradiometers. As already mentioned, the investigation of the acetylene flame with these two instruments was for the purpose of testing the quartz-lens outfit as a spectroradiometer and for obtaining data on the acetylene spectrum in the extreme violet. The data pertaining to these two spectroradiometers were obtained some years ago, but never published.

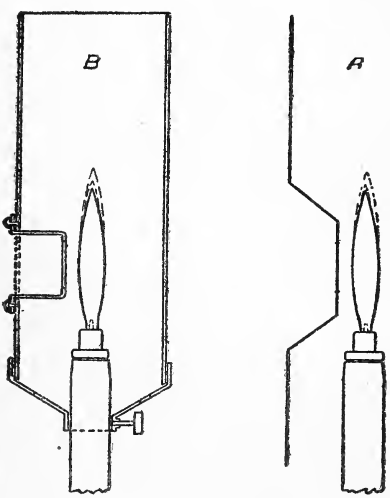

FIG. 2.—*Shields for an acetylene flame*

Spectroradiometer No. 3.—The data recently obtained relates to a spectroradiometer having (1) achromatic lenses (cemented doublets computed by E. D. Tillyer) 5 cm in diameter and 31 cm in local length, (2) a 60° prism of light flint glass, and (3) a bismuth-silver thermopile, in a monochromatic illuminator mounting.[8]

The calibration and slit-width curve of the prisms used in the two preceding spectroradiometers were obtained from the refractive indices. Not knowing the refractive indices of the flint-glass prism the scale of wave lengths was calibrated by noting the spectrometer circle readings for various helium lines, from a vacuum tube operated on a 2000-volt transformer. The spectrom-

[7] This Bulletin, 10, p. 1; 1913.

[8] This Bulletin, 11, p. 154; 1914.

eter was provided with an automatic device for maintaining the prism at minimum deviation, the fiducial point being the yellow helium line $\lambda = 0.5876\mu$ and the spectrometer circle reading being

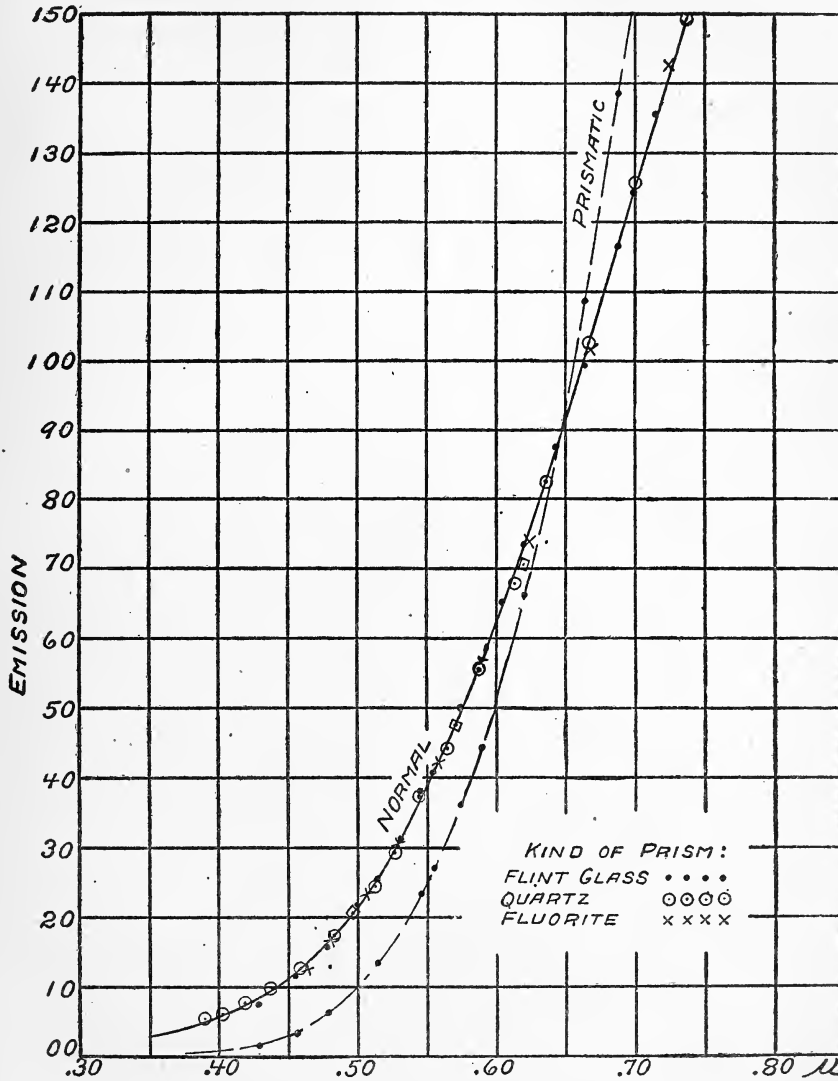

FIG. 3.—*Energy distribution in the visible spectrum of a cylindrical acetylene flame as observed with three types of spectroradiometers*

310° 00′ 00″, as shown in Fig. 4. This illustration gives the calibration curve and the curve of slit widths for reducing the prismatic energy measurements to the normal spectrum. For the information of those who are not thoroughly familiar with the

subject, it may be added that the slit widths were obtained by noting the wave lengths for any two spectrometer settings which are 10 minutes apart. The difference in wave lengths of these two settings is the slit width (in wave lengths) at the mid-point of these two spectrometer circle readings.

The flint-glass prism and the 31 cm focal-length lens produced a dispersion which is about four times that of the quartz outfit in spectroradiometer No. 1, the actual length of the spectrum being

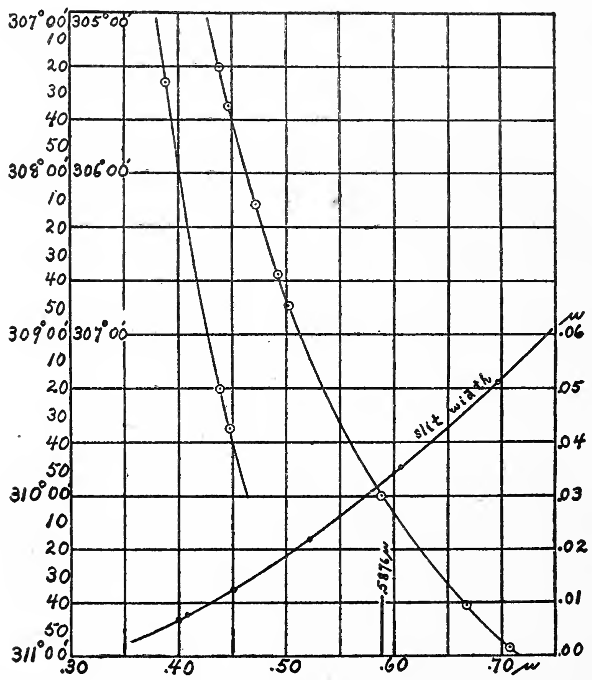

FIG. 4.—*Calibrations and slit-width correction curves of a flint-glass prism, B. S. 2425 B*

about 14 mm between the red and the blue-violet helium lines ($\lambda = 0.667\mu$ to $\lambda = 0.447\mu$). However, the wide aperture of the lenses (and prism) produced sufficient intensity so that it was possible to extend the observations into the violet, where the absorption of the prism becomes apparent, as shown in Fig. 3. Throughout the spectrum the data obtained with this apparatus are in excellent agreement with those obtained with the two preceding spectroradiometers. The slits used were, respectively, 4 and 12 mm in height, as already mentioned, and the energy curves of the acetylene flame were found in coincidence through-

out the whole region to $\lambda = 0.75\mu$ when they were in coincidence to 1 part in 180.

In view of the difficulties experienced in radiometric work it may be added that such investigations are best made in the summer (between May and September), when there is only a small difference of temperature within and without the laboratory. In this manner one can make galvanometer readings to 0.1 mm in July that can not be read closer than 0.3 to 0.5 mm in midwinter.

III. DISCUSSION OF DATA

The observations on the energy distribution of a cylindrical acetylene flame made with three different types of spectroradiometers are shown graphically in Fig. 3. They are in excellent agreement throughout the spectrum. The data read from the curve drawn through these observations are given in Table 2.

As mentioned on a preceding page, the present data supersede those published some years ago in view of the greater certainty in the reproducibility of conditions which obtain in a cylindrical flame as compared with a flat flame, to which the previously published data apply, when that flame was used edgewise.

TABLE 2

Spectral Energy Distribution of an Acetylene Flame

[Mean of 3 sets for cylindrical flame; (1) quartz prism and plano-convex quartz lenses; (2) fluorite prism, mirror spectrometer; (3) Light flint glass prism, achromatic glass lenses]

λ	E (normal)	λ	E (normal)	λ	E (normal)	
μ		μ		μ		Bray tip
350	3.1	480	17.0	625	75.7	....
360	3.3	500	21.9	640	84.7	....
375	4.0	520	27.9	650	91.1	....
380	4.4	525	29.5	660	97.4	....
400	5.9	540	35.0	675	107.5	....
420	7.7	550	38.9	680	110.9	....
425	8.2	560	42.9	700	124.6	125.8
440	10.0	575	49.8	720	138.5	140.7
450	11.4	580	52.2	725	141.9	144.5
460	13.0	600	62.1	740	152.0	155.8
475	16.0	620	73.0	750	158.9	163.7

IV. SUMMARY

This paper gives numerical data on the distribution of energy in the visible spectrum of a cylindrical acetylene flame from a certain type of burner and operated under certain conditions. In the region of the spectrum extending from the yellow to the violet the spectral energy distribution of all the flames examined ap-

pears to be the same, within the limits of observation. On the other hand, in the region of the spectrum extending from the red toward the long wave lengths, the emissivity is greatly affected by variation in thickness of the radiating layer of incandescent particles in the flame. Hence, in and beyond the red part of the spectrum the data apply only to cylindrical flames which are operated under specified conditions.

V. ADDITIONAL DATA

Since the completion of the measurements just described an opportunity was presented to determine the distribution of energy in the visible spectrum of the "Bray" tip[9] (¼-foot capacity) used by Dr. Nutting in his researches on the visibility of radiation.[10] This burner gives a cylindrical flame which is about 5 cm high and slightly greater in diameter than the one just described. This lamp has been thoroughly investigated[11] as a standard of light, giving a high intensity; and it appears to be very reliable in operation.[12] This flame may be more useful than the one just described in view of its larger dimensions. This permits operating it under various pressures without seriously affecting the energy distribution.

The light from this flame is emitted through an opening 3 mm in height. For certain radiometric work it would be better to use an opening 4 to 5 mm in height.

The distribution of energy in the visible spectrum was determined with spectroradiometer No. 3, when the flame was operated on its normal (90 mm) water pressure; also on a water pressure of 73 mm. The two energy curves coincided within the limits of experimental error, showing that, although the candlepower had changed, the color had not changed very markedly. There was a slight indication of a higher emission at 0.75 μ (redder flame) when operated on a pressure of 73 mm; but it amounted to only about 1 per cent.

The distribution of energy in the flame, from the "Bray" and the "Crescent *Aero*" burners, is the same throughout the visible spectrum to 0.70 μ, where the former begins to increase in emissivity, as given in the last column of Table 2.

WASHINGTON, January 18, 1916.

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[9] Thorn and Hoddle Acetylene Co., London, England; Crane, New York.

[10] Nutting, Trans. Illum. Eng. Soc., 9, p. 633; 1914.

[11] Jones, Trans. Illum. Eng. Soc., 9, p. 716; 1914.

[12] Copies may be obtained from the Research Laboratory, Eastman Kodak Co., Rochester, N. Y.